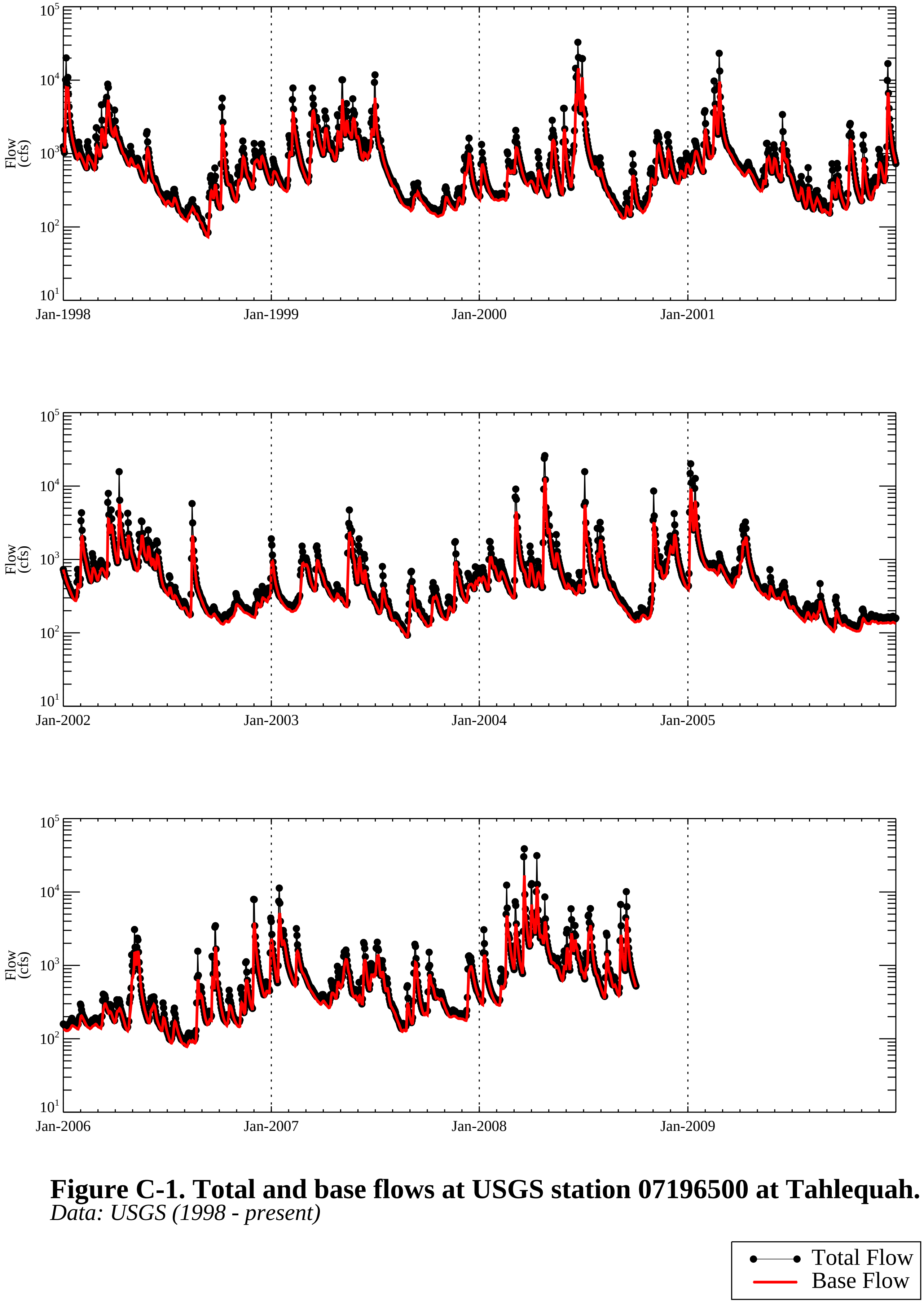

Figure C-1. Total and base flows at USGS station 07196500 at Tahlequah.
Data: USGS (1998 - present)

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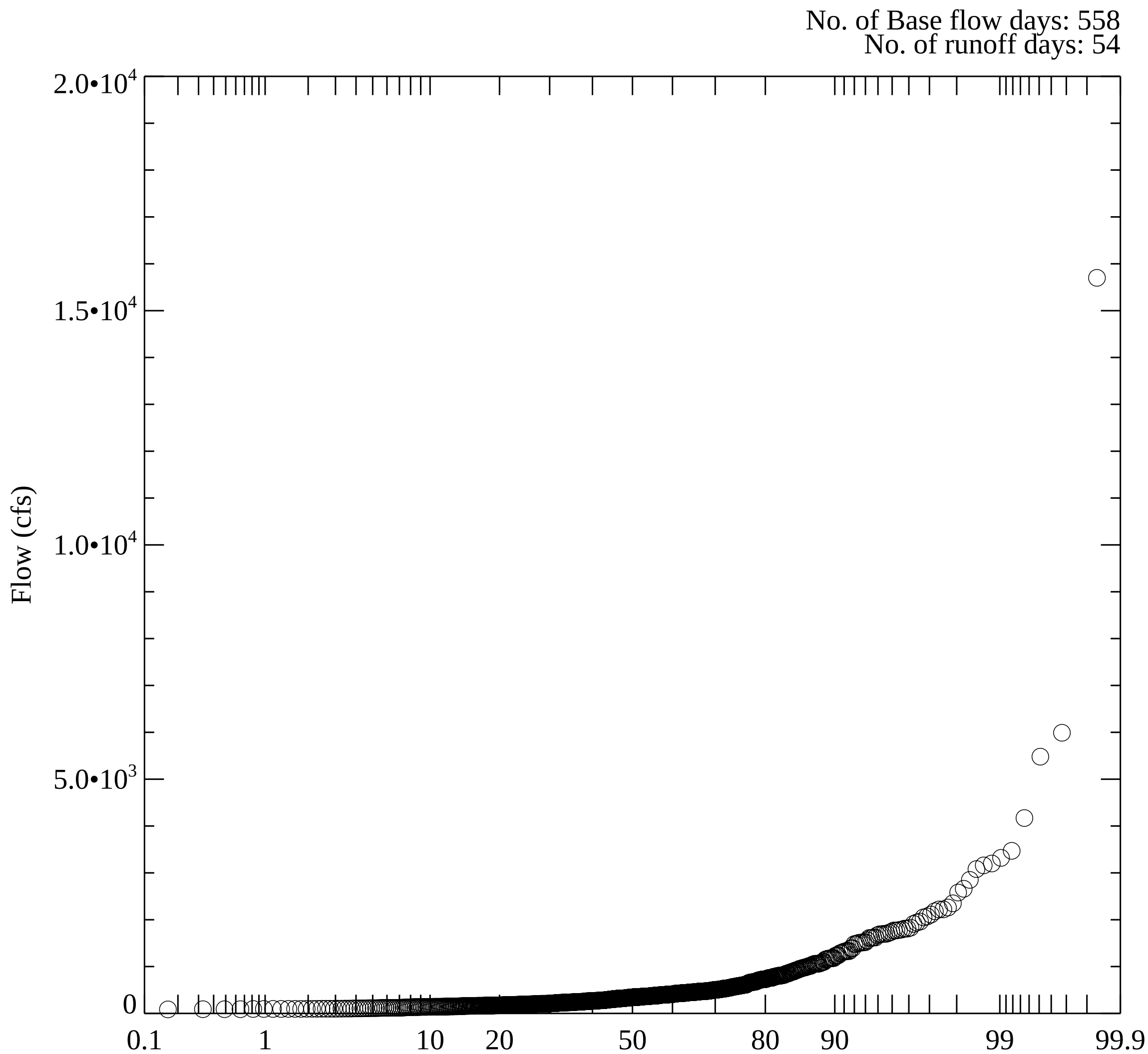

Figure C-2. Probability distribution of summer season flow at Tahlequah (2004-2007).
Data source: USGS (2004 - 2007).

APPENDIX D
Review of Potential Impact of Lake Frances

Quantitative Environmental Analysis, LLC
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APPENDIX D
LAKE FRANCES

Lake Frances is a run-of-the-river impoundment on the Illinois River located in Oklahoma, immediately downstream from the state line between Arkansas and Oklahoma. The lake was formed in 1931 with the construction of the Lake Frances dam. In 1977 the lake's surface area was measured at 2.31 km^2 with mean water depth of 1.8m and maximum water depth of 9.8m (United States Environmental Protection Agency [USEPA] 1977). By 1985, the mean depth had dropped to 1.2m with a maximum depth of 6.5m (Soballe and Threlkeld 1985) due to sedimentation of the lake. The Lake Frances dam was breached in 1990 during a flood event and one meter from the top of the spillway was lost. Consequently, the lake is now reduced to a two channel river and wetlands as shown in Figures D-1 and D-2.

Lake Frances has long been recognized as a sink for nutrients and in 1977 was considered eutrophic by the USEPA (USEPA 1997). In the USEAP study, the high loading rate of phosphorous of the Illinois River entering Lake Frances was attributed to wastewater discharges upstream. Lake Frances has a history of high nutrient concentrations and eutrophication between the 1970s until the dam breach in 1990. The primary sources of nutrients to the Illinois River during this time were upstream point sources (Soerens 2004). *released back into the water column.*

Several sources indicate that legacy phosphorus in the sediments may be currently contributing to the nutrient load in the Illinois River:

> *At the time of the dam collapse the lake had experienced a high degree of siltation with sediment levels being over 15 feet at the dam. All of the lake bed (approximately 560 acres) is now exposed with several hundred thousand cubic meters of nutrient-enriched sediment being subject to removal by river flow.* (Haraughty 1999)
>
> *This study showed the potential for bottom sediments in Lake Frances to increase phosphorus transport at the Illinois River, especially if the water column dissolved phosphorus concentration from Lake Frances decreases.* (Haggard and Soerens 2006).

In a study by Etta et al. (2006) evaluating impacts of wastewater treatment plant effluent discharges on dissolved phosphorus concentrations and sediment interactions in effluent-dominated Ozark streams (tributaries to the Illinois River in Arkansas), the researchers found:

> *…dilution-corrected SRP concentrations often increased after effluent P reductions, suggesting that legacy P stored within the stream reach was released back into the water column. Haggard et al. (2005) showed an internal P loading mechanism in an Ozark stream when effluent P concentrations were low (< 3 mg/L). Many other studies have shown that P-saturated wetland sediment release P to the water column when dissolved P concentrations are low (e.g. see Novak et al., 2004; Fisher and Reddy, 2001). It is not known how long P may be released from stream sediment back into the water column, maintaining elevated SRP concentrations.*

The State of Oklahoma, as represented by Mr. Derek Smithee, Chief of Water Quality for the Oklahoma Water Resources Board (Smithee Deposition 2008) is concerned that stored nutrients in Lake Frances may be impacting water quality downstream of Lake Frances. Mr. Smithee stated that he believes there are significant quantities of phosphorous and nitrogen stored in the current streambed and historical lake bed of Lake Frances and when the Lake Frances dam broke in 1990, nutrients released impacted the water quality in Lake Tenkiller.

During Mr. Smithee's recent deposition, Mr. Elrod asked about the deleterious impact on downstream water quality when the dam broke in 1990 due to stored nutrient releases (Smithee Deposition 2008). In response, Mr. Smithee clarified that the issue was:

> *nutrients that had been sequestered in the sediments over the decades would be released through re-channel cutting back into the river and thence to Lake Tenkiller, and because of this huge influx of nitrogen and phosphorous, the river and the lake would have significant algae problems…*
>
> Asked if that concern became true, Mr. Smithee responded,
>
> *We did not see, over the long run, the data doesn't really show over the long run significant increases in algae in the river. Although the effect of that on the lake is, that is arguable.* (Lake referenced was clarified as Lake Tenkiller).

Asked if he had reached conclusion regarding the impact on Lake Tenkiller and if losing a dam at Lake Frances had an impact on Lake Tenkiller's phosphorous problems, Mr. Smithee responded:

Yes. (Smithee Deposition 2008)

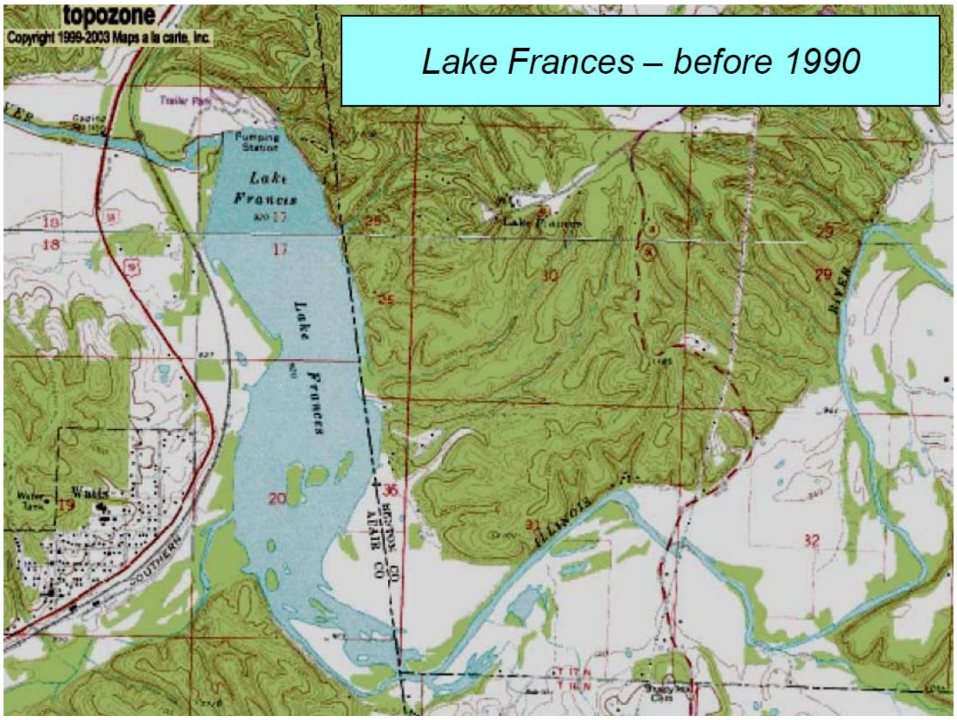

Figure D-1. Lake Frances before 1990 (Soerens 2004).

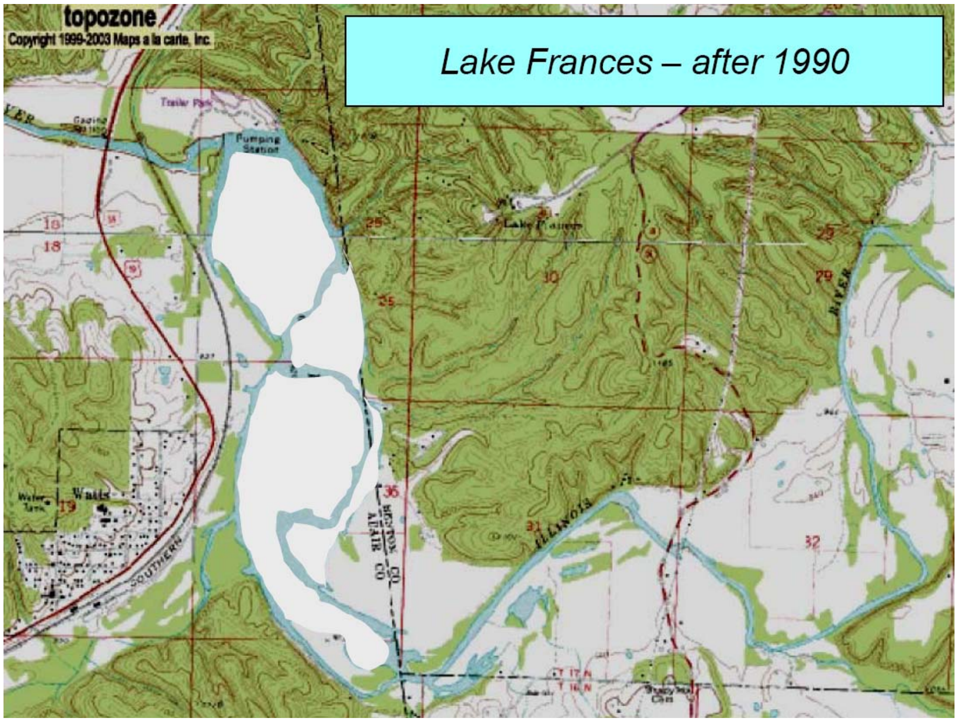

Figure D-2. Lake Frances after 1990 Dam Break (Soerens 2004)

Investigations into Lake Frances Contribution of Phosphorus Load to the Illinois River

The Illinois River near the Arkansas-Oklahoma state line is sampled by four different agencies (three in Arkansas, and one in Oklahoma) using different methods for sampling and load determination. In Arkansas, the Arkansas Department of Environmental Quality (ADEQ) takes grab samples every other month and calculates loads by averaging concentrations. The U.S. Geological Survey (USGS) takes composite samples 12 times per year and calculates loads using a regression model. Arkansas Water Resource Center (AWRC) takes grab samples every two weeks plus flow-weighted auto-sampler composite samples during all storm events and calculates loads by integration. In Oklahoma, regular samples are taken by the USGS in cooperation with the Oklahoma Water Resources Board (OWRB). Data collected is used by the OWRB to estimate phosphorus loads, yields, and mean flow-weighted concentrations for 3-year periods using a regression model.

Water quality monitoring in Arkansas of the Illinois River near Lake Frances is routinely done at Arkansas Highway 59 bridge crossing, upstream of Lake Frances. Routine monitoring in Oklahoma downstream of Lake Frances occurs at USGS gage 07195500. T. Soerens (2004) and others (Haggard and Soerens 2006; Parker et al. 1996) have attempted to compare loads upstream and downstream of Lake Frances to determine the contribution of Lake Frances on total phosphorus loads using the data from the various agencies. Figure D-3 illustrates one such comparison (Soerens 2004).

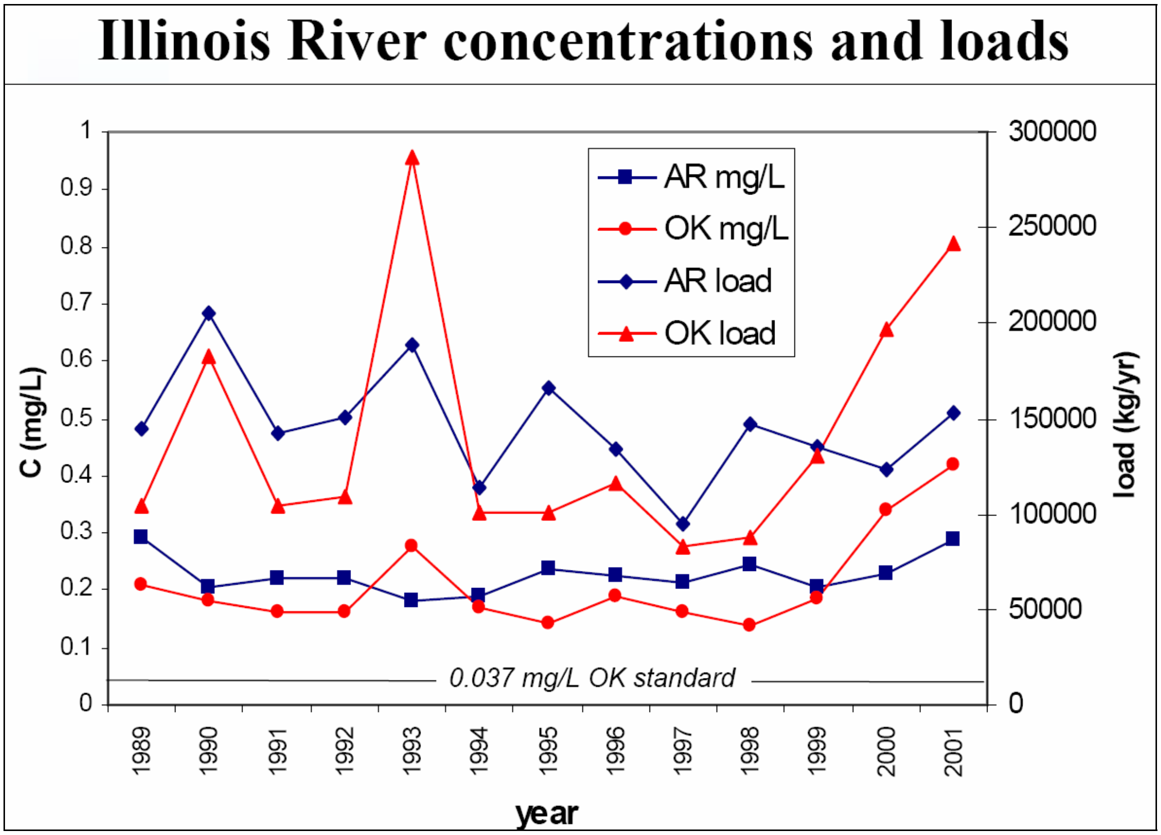

Figure D-3. Loads and Concentrations Upstream and Downstream of Lake Frances (Soerens 2004).

Soerens questioned if the difference between upstream and downstream loads is due to difference in the monitoring programs implemented by the various agencies or contributions from Lake Frances. The difference in the monitoring programs and how those differences influence the reported nutrient concentrations in the river does impact the load estimates. Prior to July 1999, only bi-monthly water quality samples were taken at the Oklahoma USGS site; whereas AWRC has been collecting grab samples every two weeks and flow-weighted storm composite samples since November 1996. Starting in July 1999, the USGS has collected surface runoff sample in addition to regular base flow samples at the Oklahoma USGS site.

The differences between upstream and downstream loads shown in Figure D-3 may be attributed to monitoring and load determination differences and/or contributions from Lake Frances due to resuspension of sediment or erosion of the exposed lake bed. Haggard and Soerens (2006) compared USGS data from both upstream and downstream locations in an effort to determine if Lake Frances sediments were contributing significantly to phosphorus concentrations in the Illinois River. The phosphorus concentrations measured during the years of 1997 – 2003 at both locations showed no significant difference between the upstream and downstream locations. However, because the water quality data taken by the USGS is not "paired" upstream and downstream of Lake Frances, Haggard and Soerens recommend that future monitoring efforts consider collecting water samples representative of the integrated stream cross-section that are "paired" during base flow and surface runoff conditions upstream and downstream of Lake Frances. When Haggard and Soerens ln-transformed the "paired" data from Parker et al. (1996) a significant difference was shown between upstream and downstream concentrations with the downstream being higher. Haggard and Soerens are concerned that legacy phosphorous in the bottom sediments may be released at rates significant enough to increased dissolved phosphorous concentrations in the Illinois River due to the internal phosphorous cycling at Lake Frances.

The State of Oklahoma has considered several studies to quantify the mass and impact of nutrients stored in the streambed and historic lake bed of Lake Frances on downstream water quality. However, as noted in Mr. Smithee's deposition (Smithee Deposition 2008), proposed studies focused on quantifying the mass of nutrient and/or erosion rates in or near Lake Frances have not been initiated due to a lack of funding.

Quantity and Transport Potential of Phosphorus from Lake Frances to Illinois River

Bounding calculations for phosphorus mass in the sediment and soil can be used to estimate the mass of phosphorus in the existing Lake Frances and associated wetlands. Maximum potential mass of phosphorus can be calculated by assuming the entire historic acreage of the lake (2.3 km^2) had an average siltation depth[1] of 3 m with an average phosphorus concentration of 740 mg/kg dry (average of two measurements taken in 2005 reported in AG database within Lake Frances, SD005A and SD005B locations). Assuming a dry bulk density of the soil of 1.4 kg/m^3 (Sauer and Logsdon 2002), the maximum mass of phosphorus in Lake Frances wetlands and river is approximately 7200 kg.

A low end estimate of the mass of phosphorus contained in the sediment and soils of Lake Frances and associated wetlands can be calculated from assuming a lower siltation depth of 1 m, yielding a mass of 2400 kg of phosphorus in the soils and sediments of the historic 2.3 km^2 lake. These estimates provide an upper and lower bound of the mass of phosphorus potentially contained in the soils and sediments that could be released into the Illinois River through natural flux from the sediment into the water column, erosion of the river banks, and loss of sediment and soil during storm events.

Phosphorus transport rates from the lake sediments to the water column can be determined from release rates measured by Haggard and Soerens (2006) from Lake Frances sediments. Under aerobic conditions, sediment phosphorus release rate was measured at approximately 4 mg m^{-2} day^{-1} and 15 mg m^{-2} day^{-1} under anaerobic conditions. Combined with the surface area at the sediment water interface, a transport rate of phosphorus to the water column can be calculated. Assuming the current surface area of Lake Frances (0.34 km^2 as determined from length and width measurements, GoogleEarth 2008), the phosphorus transport from the sediments is approximately 500 kg/year for aerobic condition release and 1900 kg/yr under anaerobic conditions. These loads are minor compared to the estimated loads entering Lake Frances between 1989 and 2001, which ranged between 100,000 kg/yr and 200,000 kg/yr (Soerens 2004).

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[1] The mean 3 m siltation depth was estimated based the reported 15 ft of siltation at the dam prior to the dam breach in 1990 and the mean depth of the lake in 1985 at 1.2 m with a maximum depth of 6.5 m. In 1977 the mean depth was reported as 1.8 m with a maximum depth of 9.8m (United States Environmental Protection Agency, 1977). The 3 m siltation depth represents a probable high end of siltation based on the 15 ft (4.5m) reported at the dam in 1990 and the maximum depth decrease between 1985 and 1977 of 3.3 m, while the mean depth for the entire water body decreased 0.6 m between 1985 and 1977.

Using Harggard and Soerens phosphorus release rates for the entire wetlands and lake area (2.3 km^2), approximately 3400 kg/yr phosphorus may be released from the sediments under aerobic conditions. Based on an approximate average of 145,000 kg/yr entering Lake Frances (Soerens 2004), Lake Frances wetlands could contribute as much as 2 - 3% additional load to the Illinois River if the wetlands were thoroughly saturated and runoff was sufficient to transport the wetland waters to the river. Additional transport mechanisms for phosphorus from the sediments and soils of current and historic Lake Frances include river bank erosion and sediment transport from overland flow and resuspension of sediments during storm flows.

Even with these load estimates, the question remains if there is enough nutrient mass and nutrient release from Lake Frances to impact water quality in the Illinois River? Mr. Smithee was asked if he thought that the 0.0375 mg/L phosphorous standard could be met below Lake Frances if the incoming water had no phosphorous. Mr. Smithee would not speculate (Smithee Deposition 2008). Haggard and Soerens (2006) indicate they believe that bottom sediments in Lake Frances have the potential to release high amounts of phosphorus and to maintain phosphorus concentrations downstream in the Illinois River elevated above the 0.0375 mg/L phosphorus standard.

Conclusions

Lake Frances is likely to be contributing some amount of legacy phosphorus to the currently load in the Illinois River downstream of the lakebed through resuspension of sediment, release of phosphorus from the sediment and erosion. The State of Oklahoma should consider further characterization of the sediments and rate of erosion to quantify the Lake's contribution of phosphorus to the Illinois River.

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